CONTROLLING Sagebrush on Range Lands

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The Intermountain Forest and Range Experiment Station is maintained by the Forest Service, U. S. Department of Agriculture, for Nevada, Utah, Idaho, western Wyoming, Montana, and northeastern Washington, with headquarters at Ogden, Utah. Present positions of the authors are respectively: Chief, Division of Range Research, Forest Service, Washington, D. C.; Professor, Botany and Range Management, Brigham Young University, Provo, Utah; Range Conservationist, Intermountain Forest and Range Experiment Station; Chairman, Department of Agronomy and Range Management, University of Nevada, Reno; and Range Conservationist, Division of Range Research, Forest Service, Washington, D. C. All of the authors were once employed by the Intermountain Station. Their subsequent experience and observations regarding sagebrush control in Oregon, Washington, Colorado, Wyoming, and Nevada are represented in this bulletin.

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CONTROLLING SAGEBRUSH ON RANGELANDS

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INTRODUCTION

Sagebrush control brings about major increases in grass production on millions of acres of western range. Getting rid of competing sagebrush and restoring a good stand of forage plants through natural or artificial seeding enables ranges to supply forage for more sheep and cattle, and is helpful in improving watersheds. In effect, new range is created on large areas; this makes it possible to obtain a superior plant cover on adjoining ranges by better grazing management practices.

Examples on many sagebrush ranges in the West show striking results from sagebrush control. In eastern Idaho, planned burning of big sagebrush [1] with a suppressed grass understory produced an increase of 69 percent in grazing capacity within 3 years. In Elko County, Nev., plowing big sagebrush and seeding to crested wheatgrass increased grazing capacity about 800 percent. In the Gunnison Valley, Colo., plowing big sagebrush and seeding increased herbage production fifteenfold. In California control of big sagebrush by spraying with 2,4-D resulted in 25 times greater grazing capacity. Innumerable other similar examples have demonstrated that sagebrush eradication can more than repay its cost.

There are approximately 96 million acres of western range in the sagebrush type. On a large part of this rangeland, sagebrush is overly dense and must be reduced before increased forage yields can be obtained. This overly dense sagebrush is largely the result of overgazing, together with drought. Sagebrush control is recommended primarily for ranges used by livestock in the spring, fall, and summer but not for those grazed chiefly in the winter. Here sagebrush, especially black sagebrush, is often a desirable forage. Likewise, control on ranges used by big game in the winter is not advocated where sagebrush is an important source of browse.

In tall, dense stands sagebrush is definitely undesirable (fig. 1, *A*). It is relatively unpalatable to sheep and cattle. It uses moisture and nutrients that should be producing good grass (figs. 1, *B* and 2). For example, 20 grasses and forbs sown adjacent to big sagebrush in northern Nevada yielded only one-third to one-fourth as much during a 3-year period as in comparable plots with sagebrush completely removed.

Sagebrush prevents grazing of grasses hidden under its woody stems and crown. It hampers movement of livestock, especially sheep. In addition, the brush snags wool from fleeces and causes lambs and calves to stray and become lost. Heavy brush makes conditions ideal for predators such as coyotes. As a result of the increasing preponderance of sagebrush over valuable herbs and grasses, western ranges now carry far fewer livestock than they should.

[1] Scientific names of all plant species mentioned are given at the end of this bulletin.

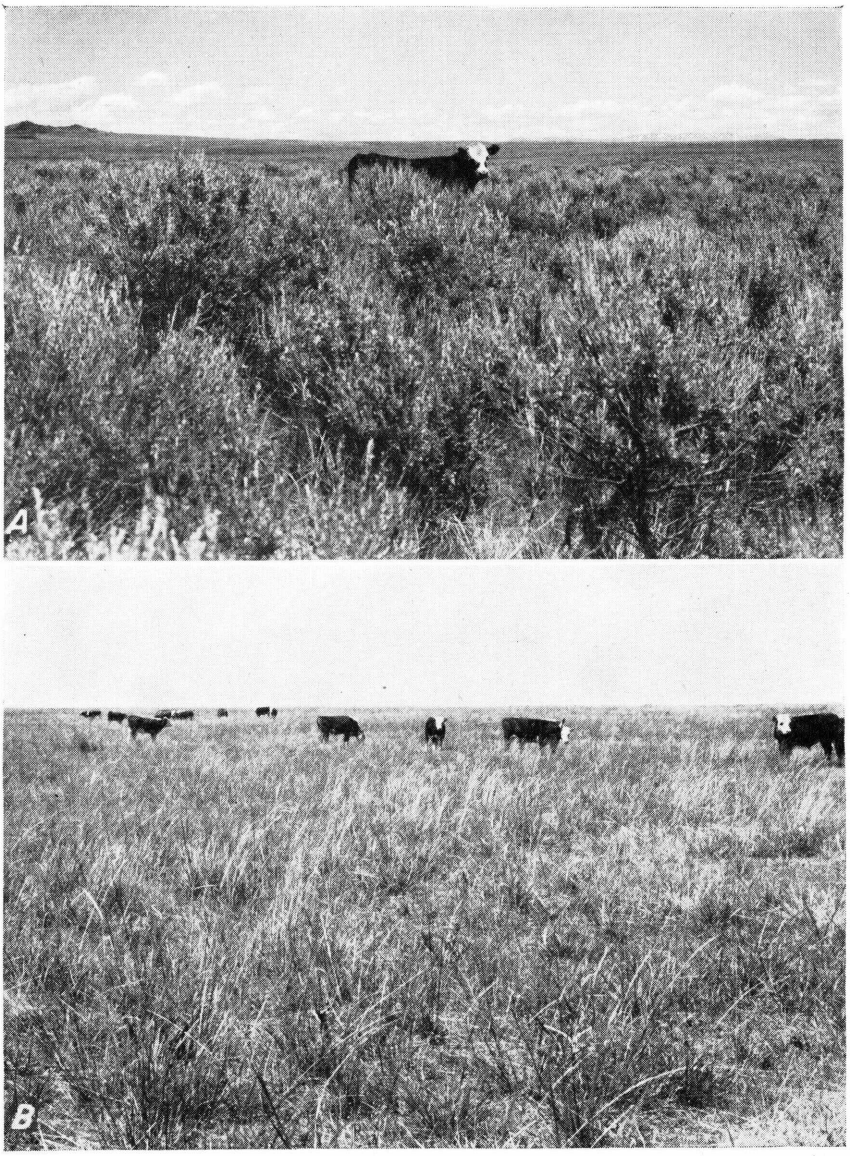

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FIGURE 1.—Dense stands of big sagebrush must be reduced before a range can be improved. *A,* Heavy stands of sagebrush such as this cover up the grass, hinder livestock movement, cause wool pulling and lamb straying, and use moisture needed to produce good grasses. *B,* Where dense stands of sagebrush have a fair understory of good native grasses, sagebrush removal by burning, railing, or some similar method will release the grasses from competition for moisture. With good grazing management, the grass can then increase and produce a good stand. Planned burning 3 years before the picture was taken has doubled the grazing capacity.

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FIGURE 2.—Where there is only a scattered understory of grass, or no grass, the range must be reseeded following sagebrush removal. This area supported a dense stand of sagebrush, like that shown in figure 1, but had no grass understory. The sagebrush was burned and the area drilled to crested wheatgrass. Three years later it could carry 15 times as many cattle as it could before treatment.

Without removal of sagebrush only slight improvement in forage yield can be expected on many ranges even after good grazing management has been practiced for 15 to 30 years. Where there is little or no understory of herbs and grasses, it may take much longer. Seldom is artificial seeding worthwhile without first eliminating the sagebrush, because the grass seedlings will be severely suppressed or die as a result of competition for soil moisture with established sagebrush.

There are many shrubby species of sagebrush, all of which are often called just "sagebrush." Big sagebrush is by far the most common. Associated species are silver sagebrush, threetip sagebrush, low sagebrush, and black sagebrush. Black sagebrush is an excellent browse on winter range, but on spring-fall and summer ranges it may not be considered valuable. These associated species may be locally more abundant than big sagebrush and methods of control may need to be altered to fit them. This publication includes the best available information on methods that could be used for these species, where the methods differ from those recommended for big sagebrush. Methods for the control of sand sagebrush, a Southern Great Plains shrub, are described in other U. S. Department of Agriculture publications, which may be obtained by writing to the Southern Great Plains Field Station, Woodward, Okla.

In the past 20 years sagebrush control has been carried out successfully on 1½ to 2 million acres. This is only a beginning, for the success of this operation and the knowledge gained will lead to application on many more millions of acres.

Most of the completed control work has been strikingly successful; some has not. Research and experience through these successes and failures throughout the West have shown that in planning for sagebrush control, the following items should be considered: (1) Where, (2) when, (3) how, (4) grazing management afterward, and (5) the need for regrassing afterward. The purpose of this bulletin is to make information on these items available for use by ranchers, public land administrators, and other land managers. By applying this information, they can eradicate sagebrush on large tracts more quickly and efficiently.

WHERE TO CONTROL SAGEBRUSH

Two conditions of sagebrush range may warrant control work. In the first, a dense stand of sagebrush suppresses the understory of desirable forage plants and interferes with grazing by livestock (fig. 3, *A*). In the second condition, the understory of desirable grasses is lacking or is so sparse that seeding will be necessary following eradication of sagebrush (fig. 3, *B*).

On sagebrush ranges in either condition the probable returns in the form of increased forage and meat production, improved livestock management, and reduced danger of erosion determine the areas where sagebrush should be removed. Certainly it is not desirable or necessary to remove sagebrush on all of the 96 million acres of the sagebrush type. The following guides will help to determine where sagebrush control should be undertaken.

1. *Where the stands of sagebrush are dense and tall.*—Such stands of sagebrush (fig. 4, *A*) usually indicate fertile, productive soils and favorable soil moisture. High yields of grass can be expected; costs of sagebrush control will be quickly repaid. On the other hand, ranges with short or scattered sagebrush (fig. 4, *B*) generally do not warrant the expense unless they fill an important place in the seasonal livestock operation or livestock management may be simplified by brush control. Scattered tall sagebrush likewise is reason for caution. Widely spaced or short mature sagebrush often indicates poor soil or precipitation. Hence, it pays to make sure precipitation and soil fertility are adequate for good forage production before control is undertaken.

2. *Where sagebrush makes up more than one-half of the plant cover.*—Such sagebrush stands definitely hinder livestock movements, and should be removed. The increase in grazing capacity to be expected is roughly proportional to the percentage of the total cover made up by sagebrush. Consequently, the ranges most heavily infested with sagebrush will most likely warrant the cost of control work.

3. *Where other undesirable plants are not important parts of the plant cover, or will be controlled.*—Other undesirable plants such as rabbitbrush, horsebrush, cheatgrass, or halogeton often make up more than one-tenth of the plant cover. Unless these plants are effectively killed at the same time as sagebrush, they may increase sharply and become even more troublesome than the sagebrush. This is especially true of rabbitbrush. If undesirable plants can be eradicated only at an increased cost, this makes the lands they occupy secondary choices for control work. Care must be taken in sagebrush control work to avoid exchanging one problem for a more difficult one.

4. *Where good grazing management will be provided.*—Good management will perpetuate increases in grazing capacity and continued freedom from sagebrush; poor management often kills grass plants and encourages

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FIGURE 3.—The amount of desirable forage species in the understory determines the need of seeding after sagebrush control. *A*, Desirable forage plants are suppressed. With removal of the competition by big sagebrush and with good grazing management the desirable plants would develop a satisfactory stand. *B*, The desirable forage plants are lacking or make up less than one-fifth of the plant cover. Here seeding is needed after sagebrush eradication to restore a grass cover, prevent reinvasion by sagebrush, and keep out other undesirable plants.

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FIGURE 4.—The density and volume of sagebrush growth is a good indication of the productivity of the site. *A,* Dense, tall stands of sagebrush such as this indicate sites that will produce an abundance of grass and easily repay the costs of sagebrush control. *B,* Scattered stands of short sagebrush usually indicate poor soil or low precipitation. Low forage production can be expected.

the rapid return of sagebrush and other undesirables. Thus, to be sure that the expense of sagebrush control is repaid by increased forage yield, it is necessary to plan and carry out good grazing management as a part of the control program.

5. *Where seeding will be done promptly, if needed.*—Removing the sagebrush is of little value unless a satisfactory stand of grasses can be established by natural or artificial means. Reseeding is usually needed where less than one-fifth of the total plant cover is composed of desirable plants. Many sagebrush ranges in this category, however, should not be cleared because their steepness of slope, rockiness, extremely poor soils, or arid conditions do not permit seeding by known methods. Moreover, it is seldom desirable to remove sagebrush from more range than can be seeded within the first year afterward.

6. *Where soils do not erode easily and slopes are less than 30 percent.*—Where danger from wind or water erosion is high, the damage done as a result of sagebrush removal (fig. 5) may more than outweigh the expected improvement in grazing capacity unless a method of sagebrush control is used which will not expose the soil dangerously. Practices such as leaving debris on the soil surface or removal of sagebrush in strips 200 to 500 feet wide, along the contour or at right angles to the prevailing wind, may be used as a safeguard against water or wind erosion. After a good grass cover has been developed on these strips, the brush between should be removed. It should be remembered, however, that sagebrush plants, alone or in strips, are a seed source for potential reinvasion.

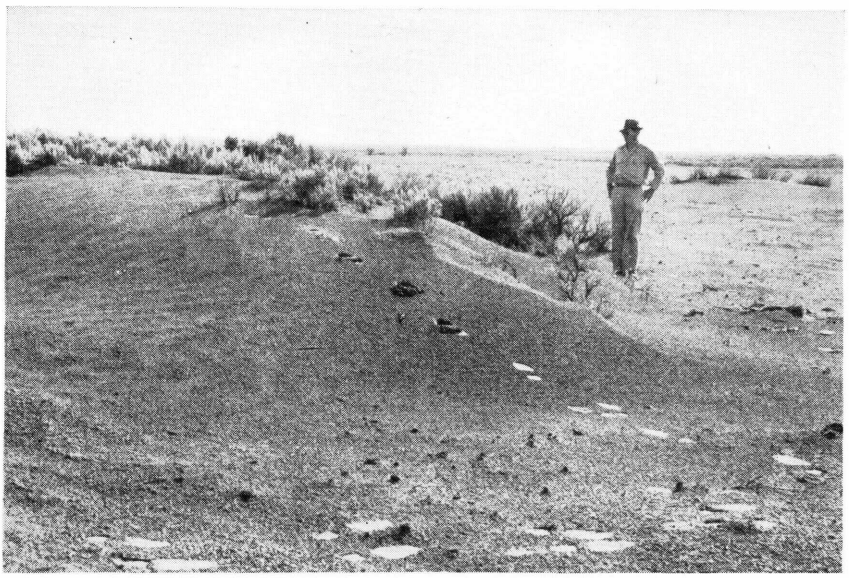

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FIGURE 5.—Sagebrush control should be applied with caution on light soils such as this, where wind erosion may be serious. Here an accidental burn has removed the protective sagebrush cover and allowed the sandy loam soil to blow and form dunes 3 feet deep. On adjacent areas, up to 8 inches of soil has been removed by wind. To avoid erosion, planned burning could have been done in strips, or other control methods used.

7. *Where sagebrush is not needed as forage for livestock and big game, or as upland bird habitat.*—Livestock, especially sheep, depend on sagebrush for browse during the winter and to a smaller extent during spring and fall on ranges where little other browse exists. On some late winter and early spring lambing ranges, the sagebrush also provides protection against blizzards and high, cold winds. On other ranges that deer, elk, or antelope use in winter, sagebrush is often a major part of their ration, especially if other browse is lacking. On still other sagebrush ranges, the sage grouse need sagebrush as nesting cover. In these places sagebrush control should not be undertaken except by methods that will thin the stand only to a desired degree.

WHEN TO CONTROL SAGEBRUSH

It is extremely important to choose the right season of the year for doing the work. This influences the percentage of sagebrush killed, the length of time that the range remains free of sagebrush, the survival of desirable grasses, the success of seeding, and the cost of the operation. The best season varies with the method used. Following are points to consider in regard to season for control.

1. *Control work should not be done during late fall, winter, and early spring after sagebrush seed starts to ripen and before it germinates.*—Operations during this period may effectively scatter and plant the sagebrush seed. Then the young sagebrush plants will come up before native forage plants have had a chance to thicken up, or at the same time as the seeded grasses (fig. 6). Studies in eastern Idaho have shown that young sagebrush

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FIGURE 6.—Thick stands of young big sagebrush such as this frequently result when control follows sagebrush seed ripening. Such stands will eventually dominate the range and sagebrush control will again be necessary.

that comes up the same spring as seeded grass may be initially suppressed but will eventually become prominent in the stand. Consequently, to increase the chances of keeping the range relatively free of sagebrush for many years, it is desirable to avoid sagebrush control work from the time sagebrush seed starts to ripen until early spring when it has germinated. At the higher elevations at which big sagebrush grows, seed begins to ripen about the middle of September. At lower elevations, it may ripen as late as the last part of November. Low sagebrush ripens seed about a month earlier than big sagebrush.

2. *Late summer and early fall is best for such methods as railing, harrowing, or rolling that uproot, crush, or break off the sagebrush.*—Sagebrush is usually brittle at these seasons and the soil is firm and dry. Under these conditions the kill is more complete than when the same methods are applied while sagebrush plants are willowy and tough.

3. *Late spring and early summer is best for such methods as plowing, disking, or grubbing that tear up or cut off the sagebrush below the ground level.*—Although these methods will kill sagebrush at any time, the equipment works most efficiently and with less breakage when there is still some moisture in the ground. Among other advantages of early-season control, moisture in the soil is conserved, the loose soil becomes firmer, and dead roots start the process of decay and conversion into soil organic matter. All of this stimulates better growth of grass following sagebrush control.

4. *The period when sagebrush food storage is low and the plant is most injured by defoliation is best for such methods as beating or mowing.*—This will probably be in midsummer or slightly earlier on most sites.

5. *Sagebrush is most susceptible to herbicides when it is growing rapidly.*—This closely corresponds to the date when understory grasses are heading out. This and other points are explained in more detail in subsequent sections.

6. *The period when associated undesirable plants will also be killed is best for reducing overall competition.*—In much of the sagebrush range, associated undesirable plants such as cheatgrass and rabbitbrush are present in substantial amounts. The best time for control of these may differ somewhat from that for sagebrush. For example, where cheatgrass forms a major part of the understory on sagebrush range, plowing should be done before cheatgrass heads are fully out. In this case, sagebrush control work cannot be continued as late in the summer as if cheatgrass were absent.

POINTS TO CONSIDER IN CHOOSING A METHOD OF SAGEBRUSH CONTROL

Many methods have been used to kill sagebrush. No one method is universally the best because sagebrush grows under widely different conditions and the sagebrush species differ. Suitability of methods will vary with density, height, and age of the sagebrush stand, associated shrub species, amount of grass understory, topography, amount of rock on the area, type of soil and its susceptibility to erosion, facilities available for doing the work, size of the area to be treated, personal preference, and many other factors.

In choosing a method the following eight points are important.

1. *Use a method that kills most of the sagebrush.*—As a general rule, the more complete the kill of sagebrush the better the method. When all sagebrush is killed, its return to the range is very slow because the seed source has been largely eliminated. Moreover, the increase in grass production is

roughly proportional to the percentage of sagebrush killed. Exceptions to the general rule of killing as much of the sagebrush as possible occur where some sagebrush is desirable on the range because of its value for protection or grazing use to domestic livestock or game, or as an aid in controlling wind erosion.

2. *Use a method that also kills associated undesirable species.*—Where the associated undesirables are so abundant as to become troublesome after sagebrush control, the method chosen should effectively control them also. Rabbitbrush or horsebrush not killed during sagebrush removal may increase so sharply as to prevent range improvement or become a worse problem than the sagebrush. In other cases, undesirable annuals present on the range such as cheatgrass and halogeton may become a serious barrier to the establishment of seeded grasses following sagebrush removal.

The definition of undesirable and desirable plants must be flexible enough to allow for differences in species of plants on the range, season of use, class of livestock or game using the range, and other factors. Palatable perennial grasses and forbs, and shrubs such as bitterbrush, are generally accepted as desirable. Snowberry, black sagebrush, and similar plants may be desirable or not, depending on season and type of use and the location.

3. *Use a method that does little damage to perennial grass remnants and other desirable plants if artificial seeding is not necessary, but if seeding is planned, use a method that kills most of the vegetation.*—On many ranges, enough desirable grasses remain to revegetate the area after sagebrush is removed. They may need only release from sagebrush competition. Seeding will be necessary if these remnants are destroyed; this nearly doubles the cost of treatment. There is also the uncertainty of getting stands from seeding. Therefore, where enough desirable plants are present to produce a good stand, they should be saved if possible.

If the aim is to improve forage quality through seeding, then particular attention should be paid to killing all plants including scattered desirable native plants that might compete with the seeded species. Past efforts to leave desirable natives to supplement seeded species have often resulted in poor seedbed preparation, and too much competition for successful establishment of seeded species.

4. *Use a method that leaves the land suitable for seeding, where seeding is necessary.*—In dense stands of sagebrush, such methods as spraying with herbicides or undercutting with grubbers and root planes leave a barrier of dead woody material that makes it difficult to use grain drills. Additional operations are often necessary to break down this woody material before drilling.

5. *Use a method that is widely applicable.*—Where extensive tracts of range are to be treated, a method that is effective for killing young and old sagebrush, on either rocky or rock-free soil, and on either steep or level ground is much more useful than one applicable only to localized conditions.

6. *Use a method that utilizes readily available equipment adapted to other uses.*—Unless a large amount of sagebrush control work is to be done, purchase or construction of expensive equipment for this purpose alone may not be warranted. It is usually better to use readily available equipment, even though it takes longer to do a good job. Often, however, the cost of recommended machinery is more than repaid by the more efficient eradication achieved. In many instances several individuals can purchase more costly machinery cooperatively, thereby reducing cost per acre and securing better sagebrush control.

7. *Use a method that will not increase erosion hazards.*—Some methods destroy all woody material and litter or cover it with soil to such an extent that wind and water erosion become serious hazards. Where soils are light and subject to drifting, or on slopes where water erosion is likely to occur, it is advisable to choose methods that will leave litter and plant material as a protective covering on the soil surface.

8. *Choose a method that is economical* but also satisfies any of the seven points above that may apply to the area to be treated. For example, if a high sagebrush kill and a good seedbed are necessary, use the cheapest method that will give an adequate sagebrush kill and a satisfactory seedbed. Supervision and labor; transportation of men, equipment, and materials; interest on investment; initial costs of new equipment; equipment operation, repair, and depreciation are all to be considered in calculating costs.

Costs vary with method. However, costs of applying a single method can vary more widely, as a result of differences in experience, care in planning the job, and size of area treated.

Other values of rangeland must be examined when considering relative costs of different methods. For example, where watershed values are high and danger of erosion is present, it may be desirable to choose a method that leaves sagebrush litter on the soil surface, even though it costs more than some other adaptable method.

METHODS FOR CONTROLLING SAGEBRUSH

Both mechanical and nonmechanical methods have been used for the control of sagebrush. Most methods are mechanical. Some employ equipment such as the one-way disk (wheatland type) plow and the offset disk or road ripper that were built for other purposes; some employ equipment such as the brush cutter and beater that were built for other types of brush; and a few employ equipment such as the sagebrush rail, pipe harrow, and brushland plow that were designed specifically for sagebrush control. Some methods, including burning, flooding, and spraying with herbicides are essentially nonmechanical.

The methods most often used for control of sagebrush on rangelands are plowing or disking with the brushland plow, offset disk, or one-way disk plow; railing; harrowing with the pipe harrow; beating; grubbing; burning; and spraying with herbicides. A summary of advantages and limitations of these methods is presented in table 1. These seven methods are fully described and five other methods are briefly considered in the following sections.

Planned Burning

The use of fire to control sagebrush is one of the oldest, most widely adaptable, and least expensive methods. It is also the most frequently misused. To insure range improvement it must be used skillfully. Proper precautions must be taken in selecting the area to be burned and the time of burning, and in controlling the fire; otherwise range deterioration may easily result.

Simple, practical rules and guides on where, when, and how to burn, and the grazing management to use after burning are presented in U. S. Department of Agriculture Farmers' Bulletin No. 1948, "Sagebrush Burning—Good and Bad." This bulletin will be helpful for anyone considering the use of fire for sagebrush control.

TABLE 1.—*Summary of limitations and advantages of the seven most common methods of big sagebrush control*

Item	Method of control			
	Planned burning	Plowing or disking	Railing	Harrowing
Kill of big sagebrush.....	95 to 100 percent of all ages.	70 to 99 percent of old; slightly less of young.	30 to 80 percent of large old; 15 to 50 percent of young flexible.	30 to 70 percent of old brittle; 10 to 30 percent of young flexible.
Kill of associated undesirable plants.	Not effective on sprouting shrubs and some annuals.	Usually not effective on sprouting shrubs; good on cheatgrass.	Not effective on sprouting shrubs or annuals.	Not effective on sprouting shrubs or annuals.
Effect on desirable forage plants.	Low kill of grass, 30 to 40 percent loss in vigor first year. Nonsprouting shrubs killed.	Kills all except those that sprout or spread by rootstocks.	Damage slight except for pedestaled grasses and nonsprouting shrubs.	10 to 20 percent of bunchgrasses uprooted; damage to bitterbrush slight.
Ease of seeding after treatment.	Easily done with drills; firm seedbed.	Easily done with drills; seedbed may be loose.	Not easily drilled unless piles of brush burned. Poor covering for broadcast seed.	Seed broadcast ahead of harrow well covered; drilling difficult.
Adaptability to terrain and soil.	No limit except as imposed by fire danger and erosion hazard.	Limited to little or no rock except with brushland plow.	Breakage high where large, embedded protruding rock occurs.	Primarily suited to quite rocky ground and rough terrain.
Availability of equipment..	Equipment needed generally available; experience primary need.	Plows and disks commercially available; brushland is custom made.	Not commercially available; easily built in farm shops.	Not commercially available, can be built in machine shops.
Effect on erosion hazard...	Exposes soil, destroys litter; avoid high hazard areas.	Exposes soil to moderate degree.	Debris left protects soil except in spots.	Usually decreases hazard.
Cost of control (1952 costs).	$0.50 to $2 per acre on tracts of 1,000 acres or more.	$3 to $5 per acre.....	$0.50 to $1 per acre one-way on large tracts.	$3 to $5 per acre.

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TABLE 1.—*Summary of limitations and advantages of the seven most common methods of big sagebrush control*

Item	Method of control		
	Beating	Grubbing	Spraying
Kill of big sagebrush	50 to 90 percent of large old; 30 to 60 percent of young flexible.	90 to 99 percent for all age classes	70 to 95 percent of large old; slightly less of young.
Kill of associated undesirable plants.	Not effective on sprouting shrubs or herbaceous species.	Effective on shrubs if cut 4 to 5 inches deep; on annuals at a shallow depth.	Not satisfactory with rabbitbrush, horsebrush, or cheatgrass.
Effect on desirable forage plants.	No serious damage to herbaceous plants; nonsprouting shrubs damaged.	Rhizomatous [1] grasses little damaged; bunchgrasses killed except where cut deep in moist soil.	Grass not damaged; many forbs and nonsprouting shrubs may be damaged.
Ease of seeding after treatment.	Can be drilled unless brush heavy; broadcasting before often successful.	May be necessary to clear brush before a drill can be used.	Standing dead brush may be barrier to drilling.
Adaptability to terrain and soil.	Limited to rock-free or slightly rocky sites.	Limited to level and rock-free areas	Virtually unlimited.
Availability of equipment	Commercially available	Commercially available	Commercially available.
Effect on erosion hazard	Mulch left may decrease hazard	Slight if any	Slight if any.
Cost of control (1952 costs)	$3 to $8 per acre	Approximately $6 per acre	$3 to $6 per acre.

[1] Sprouting from roots or spreading from rootstocks.

Thousands of acres of sagebrush range are burned over by accidental fires each year. Proper grazing management and seeding, where needed, may be effective methods for restoring a good forage cover to these areas.

The advantages and limitations of planned burning for sagebrush control are evaluated under the eight points previously listed for choosing a method, as follows.

Kill of sagebrush.—If burning is done properly, it gives a complete kill of young and old plants of big, low, and black sagebrush. Kill of threetip sagebrush is high, but a small percentage of the bushes may sprout from the base. Kill of silver sagebrush, which sprouts readily from the stem base and roots, is generally low.

Kill of associated undesirables.—Associated sprouting shrubs such as rabbitbrush, horsebrush, and snowberry are usually not killed by planned burning. Under some circumstances good kills of rubber rabbitbrush have resulted from late summer burning, but this result is not consistently obtained. Early or midsummer burning of cheatgrass will bring about a much reduced stand in the spring of the following year; burning in the late summer or early fall is less effective.

Effect on desirable forage plants.—Damage to most desirable forage plants is fairly low. If burning is done after the principal perennial grasses mature seed, reduction in their vigor the following year is not likely to exceed 30 or 40 percent. On the other hand, Idaho fescue and bitterbrush (at some locations) have been severely damaged by burning, regardless of the season. In eastern Idaho and parts of Utah, high percentages of bitterbrush have later sprouted from the stem base, particularly with light burning or on moist soil.

Ease of seeding afterward.—Where seeding is necessary afterward—except on rough and rocky areas, or on slopes over 30 percent—seed is easily planted by use of a grain drill (fig. 7). Where land is too rocky or

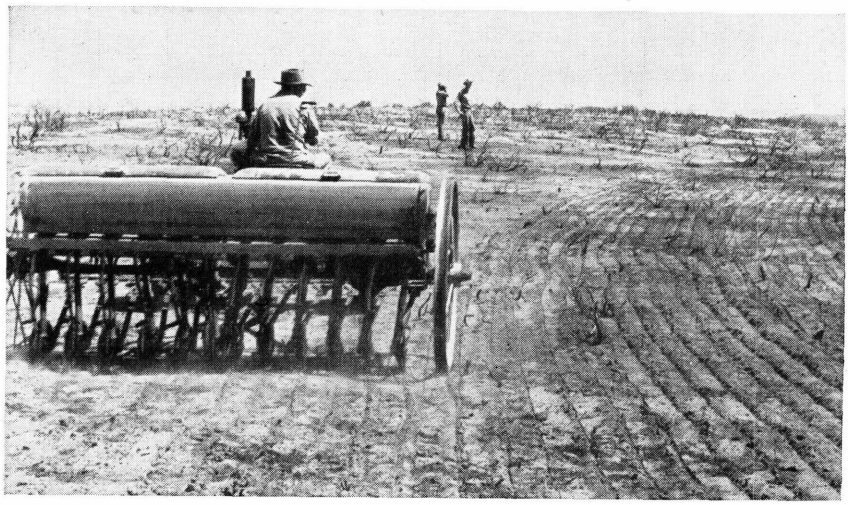

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FIGURE 7.—Planned burning on this area removed a dense stand of sagebrush that had little value for grazing. After burning, the more level, relatively rock-free areas were drilled without further preparation. Good stands of grasses resulted.

steep for drilling, the seed can be broadcast and covered. A heavy pipe harrow can be used to stir the soil and provide a covering for the broadcast seed. Sagebrush ashes alone are not deep enough to provide good seed covering.

Adaptability to terrain and soil.—Excluding hazard of erosion, burning is widely applicable regardless of rockiness of soil, steepness of slope, or irregularity of terrain. It must be possible, however, to construct a wide, safe fireline.

Availability of equipment.—Bulldozers or graders for clearing firelines and torches for setting fires are readily available.

Effect on erosion hazard.—Debris and litter are largely consumed by the fire and the soil is seriously exposed to erosion. Consequently, burning should not ordinarily be used on slopes steeper than 30 percent or on soils that blow or wash readily.

Cost of control.—For tracts of 1,000 acres or more, the cost of sagebrush control by planned burning is $0.50 to $2.00 per acre, on the basis of 1952 wages and equipment rental rates. This includes approximately $120 to $160 per mile for constructing firelines, the direct cost of burning the area, and the cost of leasing additional range for one or two years to permit protection of the burned area.

On tracts of 500 acres or less, unless roads and cultivated land or natural firebreaks are available, the cost of planned burning equals or exceeds that of mechanical methods such as plowing or disking. Suitable tracts within plowed areas can be safely burned, at much lower costs.

General adaptability of planned burning for sagebrush control.—Planned burning is most useful on fairly level tracts of 1,000 acres or more, either to permit the increase of perennial grasses already present or to prepare the land for seeding. Many stands of sagebrush, however, can be burned only under conditions of extreme fire hazard. Under weather conditions that make burning relatively safe, such stands cannot be burned because the sagebrush stands are too open and they lack an understory of grasses to carry the fire. On some ranges, where the erosion hazard is high or the dominant perennial grasses are subject to serious damage, burning should not be used.

Although burning sounds simple, it is one of the most difficult and dangerous methods. To use fire properly and safely, it is necessary to have experience in the behavior of fire, the conditions suitable for starting it, and methods of fire control. Moreover, a large number of men with some experience must be on hand to insure keeping the fire under control. In all cases there should be strict compliance with State and county laws regarding burning. *Fire is a dangerous tool for the inexperienced person to handle,* but is a valuable one when intelligently used.

Plowing or Disking

During the last 15 years plowing or disking has become the most commonly used method for sagebrush control. The three implements used widely for the purpose are the one-way disk plow (wheatland type), the heavy offset disk, and the brushland plow (figs. 8, 9, and 10).

A 40- to 45-horsepower tractor and a plow or disk with 10-foot cutting width form a convenient unit for killing sagebrush under most conditions. The plow or disk should weigh at least 300 pounds per foot of cutting width,

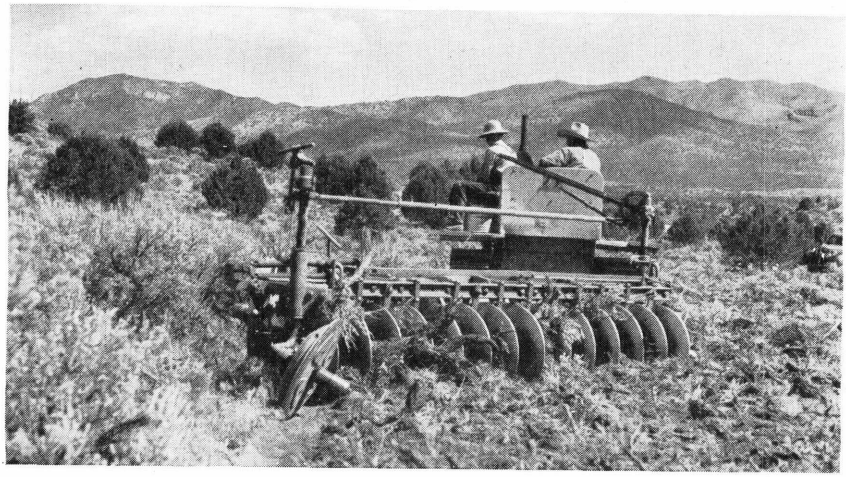

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FIGURE 8.—One-way disk plow being used on rock-free ground to eradicate big sagebrush in preparation for seeding.

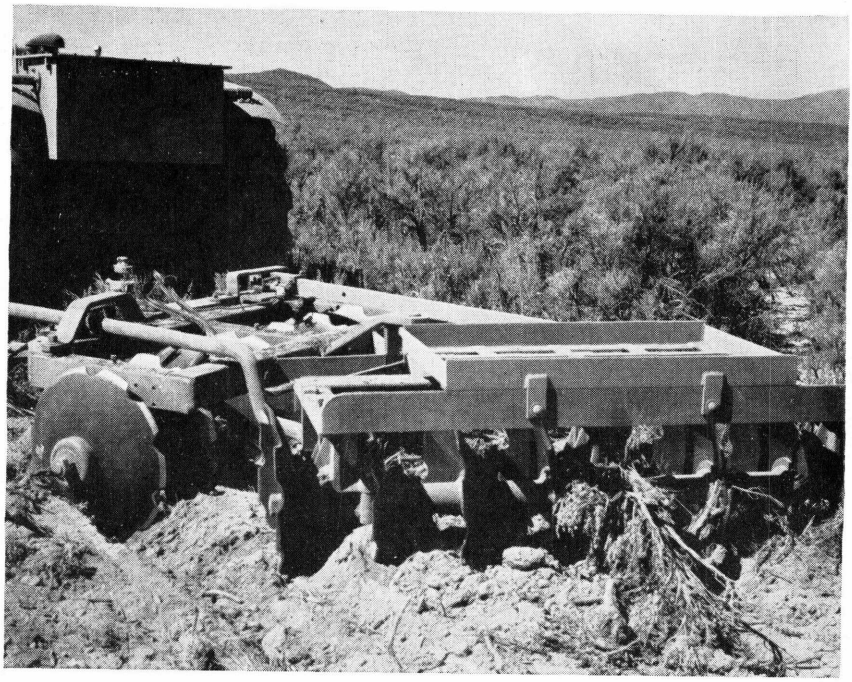

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FIGURE 9.—Heavy offset disks make good sagebrush kills and prepare a good but loose seedbed. They cut well in hard-packed soils. They should be used only on relatively rock-free areas.

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FIGURE 10.—The brushland plow is especially useful for the control of big sagebrush preparatory to seeding where some rock is present. The pair of disks on the left side is rising over a rock. Sturdy construction and the separate mounting of each pair of disks permits this implement to be used on moderately rocky land without excessive breakage.

and be equipped with disks preferably 28 inches in diameter. However, implements with 24- and 26-inch disks have done good jobs. Use of a tractor with 3 to 5 horsepower per foot of cutting width is ordinarily advisable, but the power requirement varies widely with soil conditions, amount of soil moved, density of brush, and topography.

The heavy offset disk, especially one weighing 500 pounds or more per foot of cutting width, requires more draft power than either the one-way or the brushland plow, because lacking adequate depth control it usually moves more soil and moves it twice. This heavy disk is practically the only implement that is effective in killing sagebrush on heavy, compact, crusted soils, such as those in the dry-lake bottoms of northeastern California. Such lands are much more easily plowed when moisture is present near the soil surface than at other times. Crawler-type tractors are the most satisfactory, but wheel tractors of equivalent power may be substituted where the ground is fairly level and the soil is firm. Though smaller tractors can be used on level or moderately sloping ground, the greater speed and power of larger tractors usually more than offset their higher operation costs.

In order to save power, the plow or disk should cut to the least depth that will provide an adequate kill of sagebrush. Three to four inches deep is usually sufficient. Allowing disks to cut too deeply should be avoided on heavy land where a clay subsoil may be turned up and cause surface crusting, or on sites where a shallow soil lies over coarse sand or gravel. Moreover, deep plowing or disking loosens the seedbed too much. Grass seedlings root themselves better in firm seedbeds.

All plows and disks cut better, require less power, and give better brush kills in the late spring and early summer, or at other times when the ground contains moisture than when it is dry. Spring plowing also allows loose soils to settle to some extent and part of the plant material to decay before seeding is done later in the year.

Since the one-way disk plow, offset disk, and brushland plow are in general similar, their advantages and limitations will be described together.

Kill of sagebrush.—Plowing or disking, correctly done, will kill 70 to 99 percent of all except silver sagebrush. The bigger the sagebrush and the softer the ground, the better the kill. This applies even to stands 8 to 10 feet in average height. Unless plowing is deeper than is recommended for ordinary work, thick stands of young plants and silver sagebrush will not be satisfactorily eradicated. If plows and disks are properly adjusted, one plowing is effective on young and old sagebrush alike, except on heavy, compact, dry soils where plows do not cut and a considerable number of the younger plants are skipped. It may be necessary to plow such areas twice.

The brushland plow gives a slightly higher kill of brush than the one-way disk plow or ordinary offset disk. However, the heavy offset disk, weighing 500 pounds or more per foot of cutting width, often equals the brushland plow in brush kill.

Kill of associated undesirables.—Associated sprouting shrubs such as rabbitbrush are not eradicated unless the disks cut much deeper than the customary 3 to 4 inches. In some instances, fairly effective rabbitbrush control has resulted from plowing an area twice. This doubles the cost, but is usually justified where rabbitbrush covering small areas occurs in extensive sagebrush stands. Cheatgrass and other undesirable annuals generally will be effectively thinned if the work is done in the spring well before seed ripening; control will be ineffective if work is done after seed starts to ripen. Cheatgrass can also be satisfactorily eradicated by plowing after fall germination, but this is too late for sagebrush control because its seed is ripe by then.

Effect on desirable forage plants.—Nearly all perennial forbs, grasses, and shrubs, except those that spread by rootstocks or sprout from roots, are killed by plowing or disking at a depth adequate for effective control of sagebrush. These methods should be limited, therefore, to ranges that are to be seeded.

Ease of seeding afterward.—Grain drills can be used after plowing or disking, especially on rock-free or slightly rocky soils where the cover of big sagebrush was not extremely dense before the plowing. Considerable difficulty in drilling may be experienced where the brush was big and dense; here it may be necessary to broadcast the seed. Some difficulty may also be encountered in controlling depth of drilling seed on areas plowed in summer and early fall because the soil may be rather loose. Spring plowing allows the soil to settle before seeding during the summer or fall and helps to overcome this difficulty.

Adaptability to terrain and soil.—Plowing or disking with commercially available implements is limited to rock-free or slightly rocky sites on slopes of less than 30 percent. Otherwise breakage will be unduly high. The brushland plow permits treatment of more rocky sites. Plowing or disking effectively reduces the existing stand of sagebrush during any season of the year when weather and soil conditions permit the work to be done.

Availability of equipment.—Heavy one-way offset disks equipped with large-sized disks are made by several companies and are readily available. The brushland plow, designed by the U. S. Forest Service for use on large-scale sagebrush-control projects, is available on a custom-made basis, and will soon be available commercially. Addresses of suppliers of this plow may be obtained from the U. S. Forest Service, Washington 25, D. C.

Effect on erosion hazard.—Except in sparse sagebrush stands part of the debris is left on the surface to protect the soil. Ordinarily this together with the loose, absorbent soil decreases the erosion hazard. In some situations, on the other hand, the hazard of wind or water erosion is high because of slope or lightness of soil; here the use of other methods should be considered.

Cost of control.—Ordinarily the cost is moderate. One well-trained operator with a 40- to 45-horsepower crawler tractor and a 10-foot disk or plow can average 1½ to 2 acres per hour, with a minimum of 1 and a maximum of slightly more than 3 acres. Accomplishment is at its lowest where the sagebrush range is in small tracts of 10 acres or less, or the terrain is rough with slopes as great as 20 to 30 percent. Maximum acreages per hour are possible on large tracts of 1,000 acres or more where the ground is only slightly rocky and practically level.

Costs are slightly different for the three implements, and must include original purchase price, power required to pull the disks or plows, and costs of maintenance and depreciation. The original purchase price of the brushland plow will be at least twice that of offset disks or one-way disk plows of equivalent cutting width. Extremely low breakage, maintenance, and depreciation largely offset the greater initial cost. The greater adaptability of the brushland plow to rough and rocky rangelands sets it apart as the most widely useful machine. Maintenance and depreciation costs are much lower for the heavy-duty offset disk than for the one-way.

Careful operation and frequent maintenance are important in keeping breakage of all implements at a minimum.

Average costs per acre for plowing or disking under ordinary conditions, based on 1952 wages and rates for equipment rental, range from $3.00 to $5.00 per acre. Costs will be much higher on small tracts or in remote areas. Costs are generally least with the brushland and highest with the one-way disk plow as a result of differences in amounts of breakage and maintenance. Because it requires approximately one-third greater draft power, the offset disk costs more to operate than the one-way disk plow or the brushland plow. On large tracts, use of 2 or 3 sets of disks or plows pulled by a single 60- to 130-horsepower tractor will reduce plowing costs by one-fourth to one-third.

General adaptability of plowing or disking for sagebrush control.—Plowing is primarily useful on rock-free to slightly rocky ranges where seeding is to be done afterward. The heavy offset disk and one-way disk plow have proved effective in eradicating all types and ages of sagebrush, except silver sagebrush, on soils that are rock-free or with only a little rock. An extra heavy offset disk has proved the best implement for use on heavy, crusted soils. The brushland plow has proved effective not only on rock-free sagebrush lands but also on those where scattered large rocks are likely to cause breakage of one-way disk plows and offset disks.

Railing

Uprooting, breaking off, or pressing down sagebrush by pulling a heavy rail across it is one of the oldest methods of eradication. This method, widely used in the early days to clear land for farming, has been used to some extent for range improvement. In open, even-aged, mature stands the rail may need to be pulled over the sagebrush only once. Where sagebrush is dense, uneven-aged, or growing rapidly, it is usually necessary to rail in two opposite directions to secure a satisfactory kill.

There are several designs for sagebrush rails. Most of these devices are made of 60- to 110-pound railroad rail and cover a 20- to 40-foot swath. A number of types have been tested; the two recommended are the "A" and the Supp rail. The "A" rail, as the name indicates, is a rigid frame made of railroad rails and is pulled with the apex forward (fig. 11, *A*). The Supp and similar rails are straight drags of two to several sections with flexible couplings between sections (fig. 11, *B*).

The size rail that can be pulled by any crawler tractor depends upon the density of sagebrush, topography, and to some extent the rail design. The average requirement for several areas where railing has been used is 1.0 to 1.8 drawbar horsepower per foot of rail width when the rail is pulled at 2 to 2½ miles per hour.

Most rails automatically dump themselves when loaded with brush, but often some furrowing results from dragging wads of brush. Rails should not be pulled at a high speed because they may jump too often and too far over piles of brush or uneven ground, leaving many sagebrush plants undamaged. The "A" type of rail tends to push the brush to the sides and does not have to jump as often to clear brush piles as do other types of rails.

In stands of uneven-aged sagebrush, burning is often possible after railing although it was not possible before. The range is railed once; then the piles or windrows of uprooted or broken brush are set afire. The fire tends to spread from the piles to lower and younger sagebrush, increasing sagebrush kill. Removal of the piles or windrows of brush by fire makes it much easier to drill. Such railing-and-burning, however, destroys litter and organic matter, and may require a fireline around the area, thus adding to the cost.

Advantages and limitations of railing for sagebrush control are as follows:

Kill of sagebrush.—Even though kill of mature big sagebrush is 30 to 80 percent, the kill of willowy bushes seldom exceeds 50 percent and may be as low as 10 percent. Smaller percentages of low, threetip, and black sagebrush are killed, and the kill of silver sagebrush is almost negligible.

Kill of associated undesirables.—Railing is relatively ineffective in the control of cheatgrass and sprouting woody shrubs, such as rabbitbrush and horsebrush. Other methods must be used where these species are abundant.

Effect on desirable forage plants.—Most grasses and forbs are damaged little by railing. If Sandberg bluegrass or other perennial grasses are strongly pedestaled, 10 to 50 percent of the grass may be destroyed.

Ease of seeding afterward.—Railing usually provides poor covering for broadcast seed. Seeding with a grain drill is sometimes made difficult by the piles of debris remaining. Burning the piles will make drilling easier, but will expose the young grass seedlings to more wind.

Adaptability to terrain and soil.—Railing is not suited to rough terrain and is usually not economical on small tracts. On areas with occasional large boulders or rock outcrops, breakage of the rails is excessively high.

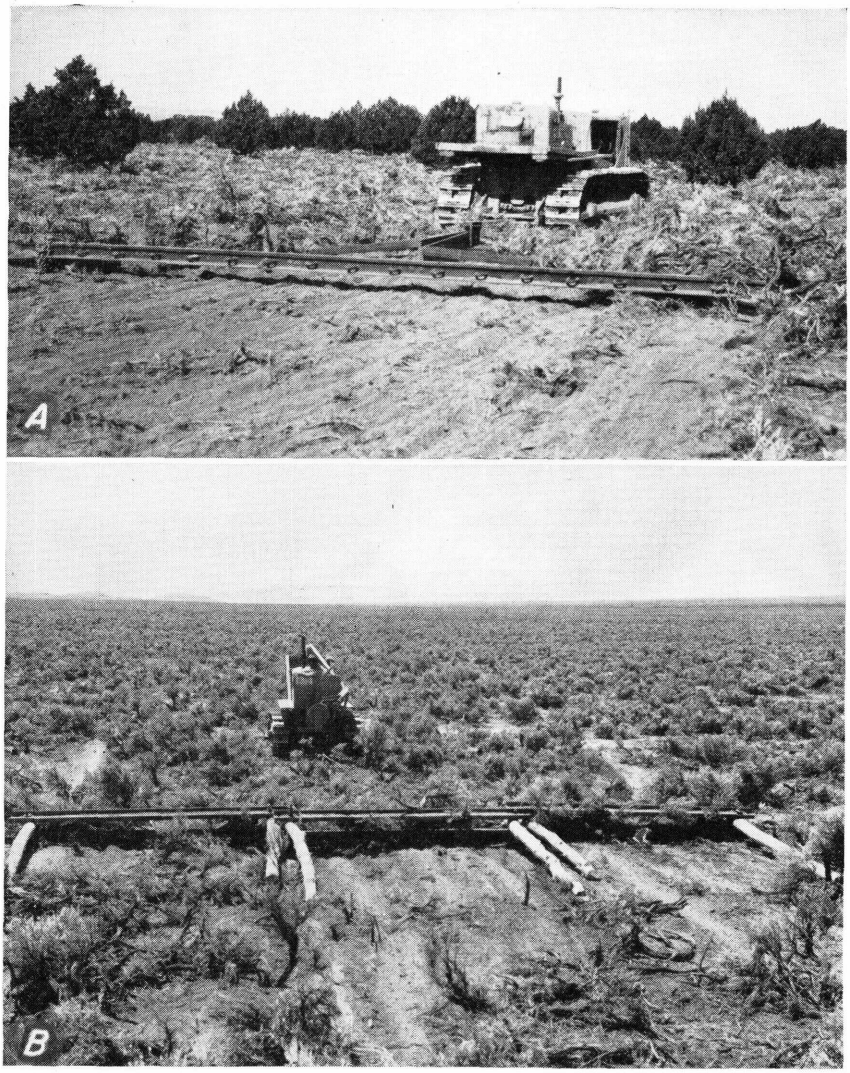

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FIGURE 11.—Rails are useful in breaking off old, mature, and brittle stands of sagebrush. *A*, An "A" sagebrush rail which throws the brush in windrows around the ends of the rail. Later models have been equipped with serrated edges on the side members and two rolling coulters on the cross member to keep the rail from swinging from side to side. *B*, The Supp rail being used for sagebrush control in Nevada.

Availability of equipment.—Railing equipment is not sold commercially but can be easily fabricated in almost any farm shop from available materials. Designs and specifications for several types of sagebrush rails can be obtained from the U. S. Forest Service, Washington 25, D. C.

Effect on erosion hazard.—Debris of uprooted or broken sagebrush plants left on the ground affords protection for 2 or 3 years to mature grass clumps

or young seedlings. The layer of coarse litter also protects the soil against both wind and water erosion.

Cost of control.—Railing is the quickest and cheapest mechanical method for use on large acreages of sagebrush. It has been done at a rate of approximately 9 acres per hour using a 53-horsepower tractor and 37-foot rail in fairly heavy sagebrush on rolling land; at nearly 12 acres per hour using a 45-horsepower tractor with a 40-foot rail in much more open sagebrush and more level land; and at 6 acres per hour using a 35-horsepower tractor and a 26-foot rail in extremely dense, uneven-aged big sagebrush. Railing an area twice in opposite directions reduces the acreage rate almost half and usually doubles the cost. Costs for railing twice over tracts of rangeland exceeding 1,000 acres during the period 1940–45, adjusted to 1952 wage and equipment rental rates, were $0.90 to $1.18 per acre. Two smaller tracts of 100 to 200 acres were railed twice for $3.80 and $1.60 per acre.

General adaptability of railing for sagebrush control.—Railing has proved satisfactory as a low-cost method for removal of old, mature, brittle stands of big sagebrush on large acreages, especially when the areas support a fair stand of native grass. It is not a desirable method for use where there are considerable numbers of young sagebrush plants; where associated undesirable plants such as rabbitbrush, horsebrush, or cheatgrass are abundant; or where seeding is necessary. However, railing followed by burning and drilling has in some cases been as successful as plowing and drilling.

Harrowing

Self-clearing pipe or log harrows, sometimes called Dixie drags, have occasionally been used for sagebrush control, but are most useful for covering grass seed on rangelands that are too rocky or rough for the use of other types of implements. They have been used to cultivate weedy alpine areas and to control rather open stands of old, brittle sagebrush on uneven ground, especially on ranges with numerous rock outcrops.

A 40- to 45-horsepower crawler tractor and a 14-foot pipe harrow make a convenient unit for harrowing. The pipe harrow is simply a series of spiked iron pipes, usually 4 inches in diameter, trailing behind a spreader bar. The pipes, being swiveled, can rotate freely and thus clear themselves of trash (fig. 12). Pipe troughs, fitted over the lead end, prevent the pipes from jumping across one another, especially on sloping ground.

Green logs 6 to 10 inches in diameter can be substituted for the iron pipes but will last only one season. The fore ends of the logs are notched for holding the chain and swivel. Discarded drill steel or similar bar steel can be used for teeth. The bars are driven through holes of slightly smaller diameter bored in the log. The teeth are held tightly until the log dries.

Harrowing the area once usually suffices to cover the grass seed. Harrowing twice will increase sagebrush kill, but will double the cost.

Advantages and limitations of pipe harrowing are as follows.

Kill of sagebrush.—Only 30 to 70 percent of old, brittle big sagebrush and a much lower percentage of younger plants are killed. Higher kills are usually obtained on rocky ground. On rocky sites, harrowing gives a fair kill of black sagebrush, a much poorer kill of low sagebrush than of big sagebrush, and negligible kills of threetip and silver sagebrush.

OREGON EXTENSION SERVICE PHOTO

FIGURE 12.—The self-clearing pipe harrow is useful for thinning sagebrush and covering grass seed on sagebrush ranges that are so rocky or rough that other implements cannot be used.

Kill of associated undesirables.—There is little eradication of such associated sprouting woody species as rabbitbrush and horsebrush. Fall treatment, after seed has germinated, results in fair control of cheatgrass.

Effect on desirable forage plants.—About 10 to 20 percent of the bunchgrasses will be uprooted by the pipe harrow. Damage to bitterbrush is low, unless it is tall and brittle. The plants are seldom killed. Plants examined 2 or more years after treatment showed stimulated sprouting and twig growth, particularly on low, spreading bushes.

Ease of seeding afterward.—Grass seed broadcast ahead of the harrow used for sagebrush control is covered rather effectively in the same operation. Sites where the pipe harrow is suitable are usually too rocky for the grain drill.

Adaptability to terrain and soil.—Pipe harrowing is about the only mechanical method that is practical on areas where rocks protrude more than 4 or 5 inches. The harrow clogs badly when used on rock-free or slightly rocky sites and becomes quite ineffective. It is readily usable on sites that are badly cut up by small gullies.

Availability of equipment.—Pipe harrows are not commercially available, but can be constructed in any fairly well equipped machine shop at a reasonable cost. In areas not reached by roads, log harrows can be readily constructed in the field at low cost with logs cut from green trees nearby;

and teeth, swivels, and cable brought in by pack horse. Designs and specifications for the pipe harrow can be obtained from the U. S. Forest Service, Washington 25, D. C.

Effect on erosion hazard.—Harrowing will usually decrease erosion. Litter and debris from uprooted and broken sagebrush left on the loosened ground surface and deposited in gullies, along with the standing brush, protects the soil better than standing brush on untreated areas.

Cost of control.—Either harrowing or plowing, on sites to which they are adapted, should cover about the same number of acres per hour at a similar cost. On 125 acres of the Manti National Forest in Utah, an average of 1.8 acres per hour was treated with a 28-horsepower tractor and a 10-foot pipe harrow. Computed at 1952 rates, the cost would be $3.00 to $5.00 per acre, or about the same as for plowing. Breakage and maintenance costs for harrowing are negligible.

General adaptability of harrowing for sagebrush control.—This implement was devised for soil disturbance, seed covering, and control of open stands of mature sagebrush on moderately to extremely rocky ground. It does a better job on rocky than on rock-free areas. The ripping and gouging action caused by the toothed pipes bouncing along among the rocks tears out some of the sagebrush, loosens rocks, and disturbs the soil enough for seed coverage. The harrow is useful for covering broadcast seed on rocky alpine areas, sagebrush burns, or on areas where sagebrush has been killed by herbicides.

The pipe harrow is an excellent complement to a plow or disk for treating interspersed areas that are too rocky for the plow or disk. By the alternate use of the two implements, all of the area that requires seeding can be treated at one time. The harrow is misused for sagebrush eradication if other machinery will give better results without undue breakage.

Beating

In recent years the beater, cutter, or stalk shredder type of implement has been widely used in sagebrush control work. These machines beat up and shred the woody and herbaceous top growth. They leave a coarse litter layer on the soil surface.

Beaters or cutters are mainly of two types. The type most extensively used to date is a beater consisting of a rapidly revolving drum or shaft, mounted between two wheels (fig. 13). To the drum are attached flexible arms or flails of chain, cable, or metal bars that swing straight out from the rapidly revolving drum. The revolving drum or shaft and its flails are driven from the power takeoff on the tractor or by separate motor. The second type of implement consists of horizontal brush-cutting blades fastened to the lower end of a revolving shaft.

For killing sagebrush these implements are adjusted so that flails or cutting blades just miss hummocks or projecting rocks. Occasional contact with the soil surface is unavoidable on uneven ground, but it should be kept to a minimum. The machines operate most efficiently and with the least maintenance and repair if the ground clearance averages 3 inches. Setting flails or blades too high results in a poor kill of small plants; setting too low results in high breakage costs. One trip over an area is ordinarily sufficient. If sagebrush is unusually dense, a second treatment may be necessary.

CATERPILLAR TRACTOR CO. PHOTO

FIGURE 13.—Beaters give a good kill of older, even-aged big sagebrush. The mulch produced is shown in the foreground. Small or low-growing sagebrush is little damaged.

The advantages and limitations of beating as a method for sagebrush control are as follows.

Kill of sagebrush.—Beating is effective in tall old stands of big sagebrush where kills of 90 percent or more of old brush are often obtained. Highest kills are under rock-free conditions on level ground. Small, young plants of big sagebrush are usually missed or little damaged by flails and cutters. Control of threetip, low, and black sagebrush is only partially satisfactory because of their low, spreading branches and the tendency of threetip sagebrush to sprout from the base. Kills of silver sagebrush are unsatisfactory because of strong sprouting from the stem base and roots.

Kill of associated undesirables.—Associated sprouting shrubs such as rabbitbrush and horsebrush and annual grasses such as cheatgrass are not controlled by beating.

Effect on desirable forage plants.—Grasses and forbs growing beneath the sagebrush are not damaged by the beaters. Bitterbrush is badly damaged but in some localities it is stimulated into vigorous sprouting from the root crown.

Ease of seeding afterward.—Grain drills may be successfully used for seeding grasses following the beater on sites where the brush is not heavy, but furrow openers will not penetrate an unusually heavy layer of woody

material. In some trials seed broadcast before beating has been covered by the mulch and good seeded stands have resulted.

Adaptability to terrain and soil.—Beaters should not ordinarily be used on soils where rocks protrude more than 3 inches above the soil surface. Maintenance and repair costs are high if the flails or cutters come into frequent contact with rocks. Moreover, beaters must be operated carefully where the soil surface is uneven or is cut up by small gullies.

Availability of equipment.—Implements of this type are commercially available. Only machines of sturdy construction should be purchased for range use.

Effect on erosion hazard.—The woody plant material left as a protective mulch on the soil surface should decrease the erosion hazard. From this standpoint, beating is the best method of sagebrush control for use where the probability of wind and water erosion is fairly high and watershed values must be guarded.

Cost of control.—The cost of sagebrush control with beaters is at least $1.00 more per acre than with plows or disks. Using a 40-horsepower wheel tractor, as much as 2 acres per hour have been covered, but 1 to 1½ acres per hour is average. Higher rates of travel are possible, but it is important that speed not exceed 3 miles per hour if maintenance costs are to remain low and efficiency of control high. Actual costs on several operations during 1951 and 1952 were $3.00 to $8.00 per acre.

General adaptability of beating for sagebrush control.—Beaters and cutters can be especially useful for control of stands of big sagebrush that are uniformly old and large, and where rocks are absent or protrude less than 3 inches above the soil surface. They are useful for the release of native perennial grasses growing beneath the sagebrush or of seeded stands being suppressed by sagebrush, or where hazard of wind or water erosion is high.

Grubbing

Mechanical grubbers, also called root planes, cultivators, or blades, have been widely used for clearing sagebrush land preparatory to farming. They have received only limited use for range improvement, but are now being used in killing rabbitbrush on rock-free land. Grubbers consist of from one to five usually **V**-shaped blades, mounted on a heavy frame suspended between two wheels (fig. 14) or mounted at the rear of a crawler tractor and hydraulically operated. The blades can be raised or lowered by either a lever or a hydraulic lift. In operation the blades are set so that they cut all roots at 4 to 5 inches below the soil surface.

Advantages and limitations of grubbing for sagebrush control are as follows.

Kill of sagebrush.—Nearly a complete kill of big, low, and threetip sagebrush of all ages will be obtained when grubbers are carefully operated so that no strips are missed. No trials have been made on silver sagebrush, but it is reasonable to believe that grubbing can give good kills.

Kill of associated undesirables.—Associated sprouting shrubs such as rabbitbrush and horsebrush are effectively controlled when the grubber blade cuts at 4 to 5 inches beneath the soil surface. The grubber type implement is the most effective so far found for eradicating rabbitbrush. In heavy rabbitbrush, a heavy chain or cable pulled in a **U**-shaped loop behind the grubber overturns the plants. This makes drilling easier and prevents the rerooting of rabbitbrush plants. Undesirable annual grasses such as

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FIGURE 14.—Rear view of one type of implement that grubs sagebrush effectively on rock-free land. This implement has been found particularly effective for control of rabbitbrush or horsebrush and the clearing of brush preparatory to farming. The blade is usually set to cut 4 to 5 inches below the soil suface.

cheatgrass will be effectively thinned only if they are grubbed after germination in the fall or before seed forms in the spring, and if the blades operate at a shallow depth, usually too shallow to be satisfactory for brush.

Effect on desirable forage plants.—Perennial grasses, forbs, and shrubs that do not spread by rootstocks are almost completely killed, except where the blades are set deep and the soil is moist. Under such conditions, associated sprouting shrubs are not killed either.

Ease of seeding afterward.—The brush will usually be left standing, unless a U-shaped loop of cable or chain is pulled behind. If this is not done, a separate operation of raking and burning may be necessary in heavy brush before a drill can be used.

Adaptability to terrain and soil.—Grubbers are useful only on relatively level and rock-free areas. Breakage is excessive wherever there are a few large rocks embedded near the soil surface. It is difficult to keep the blades operating at a uniformly satisfactory depth whenever the ground surface is uneven. Grubbers are useful where there is a heavy clay subsoil because they loosen the surface soil but do not turn up the heavy subsoil to form a surface crust, as sometimes occurs with plowing.

Availability of equipment.—Root planes, cultivators, or blades are commercially available. The heavier types are best for rangelands.

Effect on erosion hazard.—There is practically no increase in erosion hazard. Brush should not be raked and burned on sloping ground or on sandy or light soils.

Cost of control.—Costs of operating the grubber are higher than for plowing or disking under similar conditions. A 255-acre area in Utah was treated with a cultivator in 250 hours; thus the rate averaged slightly more than 1 acre per hour. Here a blade with an 8½-foot cutting width was pulled by a 50-horsepower wheel tractor. The cost, based on 1952 wage and equipment rental rates, was about $6.00 per acre.

General adaptability of grubbing for sagebrush control.—Mechanical grubbers (blades, cultivators, root planes) are useful primarily where control of rabbitbrush as well as sagebrush is necessary. Their use is limited to rock-free, deep soils where the potential production of seeded grass will justify the cost, or where conversion of the sagebrush range to cropland is the objective.

Spraying With Herbicides

During the last few years experimental spraying with 2,4-D and 2,4,5-T has produced good kills of big, low, black, and silver sagebrush. Kills of 70 to 95 percent of big sagebrush plants have been reported from California, Oregon, Wyoming, and Colorado.

The recommended procedure varies somewhat from place to place and with different species of sagebrush. In general, results show that spraying should be done when sagebrush is actively growing and there is still ample soil moisture for growth. Usually this is when native understory bluegrasses are heading out well. One or two pounds of isopropyl or butyl ester of 2,4–D or one pound of 2,4,5–T in 5 to 20 gallons of water or 3 to 5 gallons of diesel oil per acre are the rates of herbicide and carrier ordinarily used. Since the chemicals do not appear to be translocated radially in woody portions of sagebrush branches and stems, degree of kill depends largely upon how well the spray solution covers the herbage. Application of the spray solution is by ground rigs, airplanes, or helicopters (fig. 15).

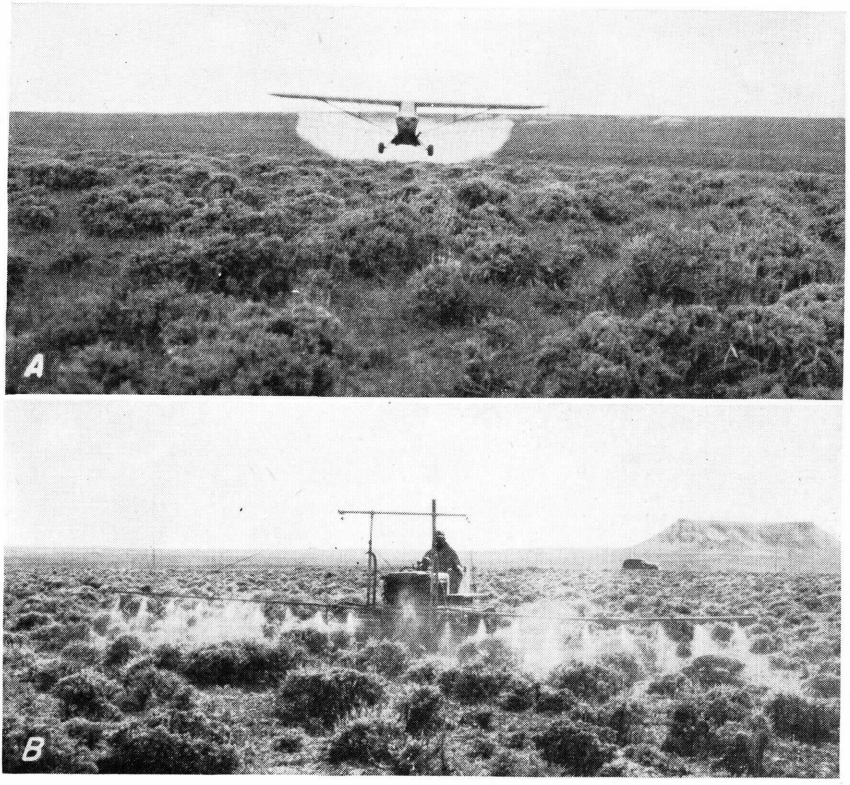

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FIGURE 15.—Herbicides may be sprayed by air or ground applicators. *A*, Airplane spraying herbicide on sagebrush in Wyoming. *B*, Ground spray outfit mounted on a crawler tractor. This outfit covers a 30-foot swath and travels 3 miles per hour.

The advantages and limitations of spraying with herbicides for sagebrush control are as follows.

Kill of sagebrush.—While results are variable, satisfactory kills of big, low, black, and silver sagebrush of all age classes have been reported. In stands of mixed ages the younger plants are least injured. Spraying produces slightly lower kills on silver sagebrush than on other species.

Kill of associated undesirables.—So far as is known, the kills of rabbitbrush, especially of the low or green rabbitbrush group, are successful only when chemicals are applied at exceptionally high rates. Pricklypear is killed, but spineless gray horsebrush and cheatgrass are not.

Effect on desirable forage plants.—Desirable perennial grasses are not damaged. Effects on desirable weeds and shrubs have yet to be studied. Bitterbrush, shadscale, winterfat, and perhaps others may be seriously damaged. Where many desirable broadleaved herbs are present, spraying is not recommended.

Ease of seeding afterward.—Where sagebrush is short or stands are open, drilling has been sucessfully done after spraying. Ordinarily it is not possible to drill in dense and tall dead stands of big sagebrush without first knocking down the dead brush with a rail or pipe harrow.

Adaptability to terrain and soil.—Spraying is widely applicable. Use of ground rigs is limited to relatively level areas, but airplanes and helicopters permit application of spray to nearly all sites. There are rather clear indications that big sagebrush control by spraying may be more effective in swales or on level bottom lands than on exposed slopes or ridge tops. Where valuable timber or cultivated crops lie near areas to be treated, care should be taken to avoid letting the spray reach them, especially with high-volatile esters.

Availability of equipment.—Many companies specialize in spraying with ground rigs, airplanes, or helicopters. Several types of equipment for ground application are readily available. Boom sprayers may need reinforcement of the booms for use on rough and rocky ground.

Effect on erosion hazard.—The erosion hazard is not increased as a result of spraying. The dead standing brush, undisturbed litter cover, and undisturbed soil and grasses do not tend to favor erosion.

Cost of control.—Costs of spraying are about the same per acre as for plowing or disking. Based on present prices of 2,4–D and 2,4,5–T or mixtures of the two, and the present cost of the carrier and of application by airplane, the total cost of spraying sagebrush with an airplane is likely to range from $3.00 to $5.00 per acre. Application with ground rigs is likely to cost about $1.00 more.

General adaptability of spraying for sagebrush control.—On the basis of present knowledge, spraying appears most useful either on ranges that have a good understory of native grass to thicken up and replace sagebrush, or on seeded areas that have been invaded by sagebrush. It may also be useful for killing sagebrush preparatory to seeding on areas where sagebrush is short or sparse.

Widespread spraying of sagebrush should be undertaken with caution. For unknown reasons, numerous failures or poor successes have resulted from large-scale spraying jobs. Lack of knowledge regarding effects of herbicides on the associated desirable broadleaved forage plants and shrubs, and on animal life depending upon this vegetation, give further reason for caution. Since new information is constantly becoming available, it

would be well for anyone considering this method to get the latest information from county agricultural agents, State agricultural colleges, or representatives of Federal agencies acquainted with range-improvement work.

Many States have laws governing the use of herbicides for plant control. Consequently, anyone planning to use herbicides for sagebrush control should make sure that the work will be done in full conformity with the laws of his county and State.

Other Methods

Many other methods have been tried in clearing sagebrush for farming or for range improvement. Because some of these methods may be useful for sagebrush control, especially if the equipment is readily available, they will be briefly described here together with their advantages, limitations, and possible application.

Mowing.—An ordinary power-takeoff mower having a heavy cutter bar, snub-nosed guards, heavy-smooth sections, and a double set of clips to hold the sections snugly against the blunt guards has been found successful for sand sagebrush control in the Southern Great Plains. Mowing must be done in June or early July. It has not, however, proved useful for other sagebrush species. Stems of mature big sagebrush are too thick, while small plants and most other species have too many branches near the soil surface that are missed by the mower. It cannot, moreover, be used without excessive breakage if there is much rock lying on the soil surface. The only application that mowing seems likely to have, other than for sand sagebrush, is in the control of young plants that have invaded seeded ranges.

Ripping.—A 2-ton self-clearing road ripper with teeth spaced 14 to 16 inches apart, pulled by a 30- to 45-horsepower crawler tractor, has been used for thinning sagebrush. With ripper teeth digging 4 to 6 inches, it breaks down or tears up much of the large and old sagebrush, but kills only about one-third or less of the young plants. About a third of the perennial bunchgrasses are killed. Though some successful stands of crested wheatgrass have resulted from broadcasting on ripped areas, usually not enough of the sagebrush is killed for successful seeding. The ripper can be used with very little breakage on sites that are too rough and rocky to plow, or for loosening up the surface of heavy, tight soils. Ripping is too costly for more than limited use in encouraging the existing grass stand to increase.

Rolling brush cutter.—The heavy type of rolling brush cutter has been tried in a limited way for sagebrush control (fig. 16). It will crush and chop up the larger and older bushes of big sagebrush, but only a few of the younger plants are killed. Associated sprouting shrubs such as rabbitbrush and horsebrush and annual grasses are not killed. The blades on the rollers are dulled quickly, especially if there is much rock in and on the soil surface. The rolling brush cutter does not prepare the site adequately for seeding. The roller with spiked teeth instead of cutters appears to be even less effective in killing sagebrush. It is doubtful that these rolling implements have any real value for eliminating sagebrush on large range areas.

Road graders or bulldozers.—These implements have been used widely on small tracts of land, primarily for clearing sagebrush preparatory to farming. Ordinarily, almost all sagebrush is killed, but the plants are mixed with dirt in windrows and subsequent disposal is difficult. Perennial

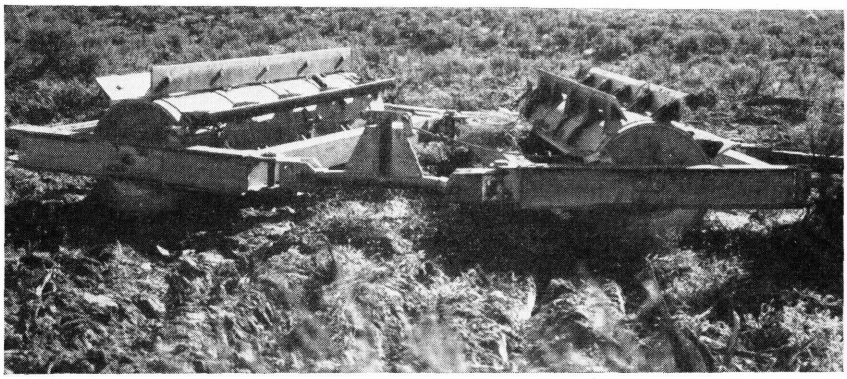

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FIGURE 16.—Rolling brush cutter being used for sagebrush control in north central Nevada.

grasses and other forage plants, except those that sprout from the roots or spread by rootstocks, are completely destroyed. The method is not effective on rocky ground or rough terrain unless much time is expended. In general, the use of these implements is too costly except on very limited tracts where other more suitable equipment is not available. Both are widely used in constructing firelines before burning.

Flooding.—This is one of the oldest but least widely applicable methods of sagebrush control. It is limited to areas where high spring runoff waters are available. Good kills of big and low sagebrush have been obtained and excellent stands of grass restored by the use of spreader ditches or similar methods for keeping the ground covered or saturated with water for 2 weeks or longer in the spring. Where spring runoff is readily available, this can be done through efficient spreading systems. Silver sagebrush is relatively resistant to flooding. Seed broadcast just before flooding results in good stands because the constantly wet soil surface enables the seeds to germinate and grow.

REGRASSING AFTER SAGEBRUSH CONTROL

Eradicating sagebrush for purposes of range improvement is of little avail unless a good stand of desirable forage plants promptly reoccupies the area. There is great need to get such a stand as soon as possible to protect the soil from erosion, prevent the early return of sagebrush in large quantity, prevent invasion by other undesirable plants, and repay the costs of sagebrush control through a rapid increase in grazing capacity.

Rapid revegetation is needed especially where burning or other methods have destroyed or buried most of the litter. The longer the soil remains exposed, the greater the difficulty to be expected in getting a stand of reseeded grass, and the greater the likelihood of serious erosion, especially if the soil is somewhat sandy or light or the slopes moderate to steep.

A good stand of perennial grasses is necessary to prevent the early return of heavy stands of sagebrush. Eradication of sagebrush is seldom complete. Plants left alive will produce seed which will lead to reinfestation of adjoining areas unless enough grasses are present in the understory or are established by seeding to control the sagebrush seedlings (fig. 17).

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FIGURE 17.—Good stands of grass reduce danger of reinvasion by sagebrush. This range was accidentally burned in 1937. The area on the left was seeded to crested wheatgrass the same year. The area on the right remained unseeded; and the next spring it bore an abundant crop of sagebrush seedlings. In 1948, the unseeded area had over 16,000 plants and produced 1,012 pounds of sagebrush foliage and twig growth per acre, compared to about 4,000 sagebrush plants and 270 pounds of herbage on the seeded range.

Good stands of perennial grasses also prevent serious invasion by other undesirable plants after sagebrush control. In Nevada the newly introduced poisonous annual weed halogeton came in on strips that had been cleared of sagebrush for range improvement. This weed is also quick to occupy burned ranges. Successful seeding to perennial grasses may not entirely prevent establishment of undesirable annuals, but these are likely to be so sparse as to provide little competition to perennials. By the second or third year native or seeded perennials should fully occupy the site.

On ranges near irrigated farm lands of Idaho, Utah, and other States, sagebrush control on lands lacking an adequate perennial grass understory may permit invasion of Russian-thistle, tumblemustard, flixweed, and halogeton. These are breeding hosts for the beet leafhopper (*Eutettix tenellus*), an insect which spreads curly top disease to nearby sugar beet, tomato, and bean crops.

Some ranges have enough desirable perennial grasses and other forage plants growing beneath the sagebrush to revegetate the area quickly after the sagebrush is killed. If these are not destroyed by control operations, and if good grazing management is used afterward, there is little need for range reseeding. As a general rule seeding is not needed where more than one-fifth of the total plant cover is made up of desirable plants, provided they are fairly well distributed (fig. 3, *A*).

There are extensive sagebrush ranges where not enough perennial grasses remain beneath the sagebrush to revegetate the area quickly (fig. 3, *B*). In these cases, it is advisable to make seeding a part of the sagebrush control job.

Seeding to desirable forage plants should also be planned where sagebrush eradication methods such as plowing or disking, ripping with closely spaced teeth, grubbing with a mechanical grubber, scraping with a bulldozer or grader, or burning destroy a high percentage of the stand of perennial grasses.

Seeding may also be desirable to improve forage quality. Where perennial grasses and other forage plants present on the area furnish forage of inferior quality or are low in production, more valuable species should be planted after eradicating the sagebrush. Where earlier spring grazing is needed than would be provided by the native grasses, it may also be desirable to seed early-growing grasses. In both these cases, sagebrush control methods that destroy a large part of the understory grasses will be needed to permit establishment of the seeded species.

Information on where seeding is likely to succeed, what species to use, how and when to plant, and what equipment to use in planting can be obtained from several State and Federal publications, or from county agricultural agents, State colleges, or local Federal officials who are acquainted with grazing management and seeding work.

MANAGEMENT OF RANGES AFTER SAGEBRUSH CONTROL

The major aim of management of ranges after sagebrush control should be to encourage continued maximum production of forage. This requires that management of grazing use should discourage rather than favor the return of sagebrush, and thus avoid the need of repeated sagebrush removal. Careful management of grazing and the judicious recontrol of sagebrush where objectionable stands recur are the principal means of achieving these aims.

A large part of the present sagebrush type had sagebrush as part of the natural plant cover. Studies show that sparse to dense stands of sagebrush are likely to become established 5 to 20 years after control. The speed and amount of sagebrush reestablishment depends upon the completeness of the stands of native or seeded forage plants, grazing management, and the percentage of the sagebrush that was destroyed. The chances for reinvasion are lessened considerably if the source of sagebrush seed is eliminated over vast areas. This is seldom accomplished with available methods; burning is virtually the only method that may give complete initial eradication.

Even where initial eradication is complete and good stands of grass develop, sagebrush will sometimes come in again. This sagebrush may originate from seed stored in the soil or on its surface, or seeds windblown or carried by animals from areas occupied by sagebrush. Usually the reestablished sagebrush stands are sparse and not objectionable, but in about one year out of five, conditions are favorable for a dense stand. Poor grazing management will, of course, permit the sparse stands to thicken and gradually form dense stands again.

Eradication of newly established sparse or dense sagebrush stands is a major problem. In some cases it pays to get rid of even the sparse seedling stands within 3 to 7 years, before the young sagebrush plants have produced a crop of seed, thereby discouraging establishment of a still thicker stand. Where a good grass understory is present, it is advisable to use spraying, burning, beating, or other methods that do not damage the grass.

Good grazing management is indispensable after sagebrush eradication, regardless of the method of control or the method of regrassing. The kind

of grazing management practiced is the most important single factor determining whether sagebrush control results in range improvement or deterioration, and how long the range remains free of dense sagebrush (fig. 18).

In grazing ranges after sagebrush control the following three recommendations should be observed.

1. Avoid trailing livestock the first fall and winter across areas where sagebrush has been eradicated. Trailing the first fall stirs up the soil and speeds erosion. After sagebrush seed has ripened, livestock are likely to carry sagebrush seed from uncleared areas, mostly in their fleece or hair, and scatter it over the cleared areas. Sagebrush seedlings that come up early the following spring will be firmly established before the perennial grasses are big enough to prevent it. Thus, trailing alone can be responsible for the early return of sagebrush.

2. Delay grazing until native grasses are vigorous and seeded forage plants are well established. Where the natural increase of native grasses is being relied upon, it is advisable to delay grazing for at least a full year. An appearance of abundant green growth the first spring is misleading. The dense sagebrush formerly screening the grass and weed understory from view has been broken down or removed, and most of the perennial grasses on the area are now visible at a glance. Thus there appears to have been a striking increase in forage production, when actually there may have been a decrease. Grazing the first spring usually delays an increase in size and abundance of the perennial grass remnants and keeps the plant cover so open that sagebrush can successfully return. Furthermore, grazing the open plant cover disturbs the inadequately protected soil and may speed wind and water erosion.

It is advisable to delay grazing of a seeded range until the first grass seed crop is cast. Grazing at an earlier date may severely damage or even pull out many of the young and weakly rooted grass seedlings. Two full years are usually required for young plants to become firmly rooted, make vigorous top growth, and produce their first seed crop. In rare instances this stage may be reached and grazing permitted by the end of the first year, but more often, because of hot, dry weather, it takes 3 or even 4 years for seeded grass to attain this stage of development.

3. It is extremely desirable to practice good grazing management after the new forage stand is well established. Whether the stand is seeded or has developed from native perennial grasses, it can easily be damaged by improper grazing practices, especially in drought years. Good grazing management will lengthen the period of good forage production following sagebrush control. Proper intensity of grazing is most important. To obtain proper grazing intensity, to insure grasses being grazed at the proper season, and to help secure proper distribution of livestock, it may be necessary to fence the seeded and improved areas and to provide better stockwater facilities. Adequate water may be provided by the development of springs, drilling wells, or hauling water by truck to portable troughs. Other recommended practices include open herding, proper location of salt grounds, and rotation grazing. These and all other practices that further good range use should be employed to help in maintaining the increased grazing capacity and maximum usability of the range resulting from sagebrush control.

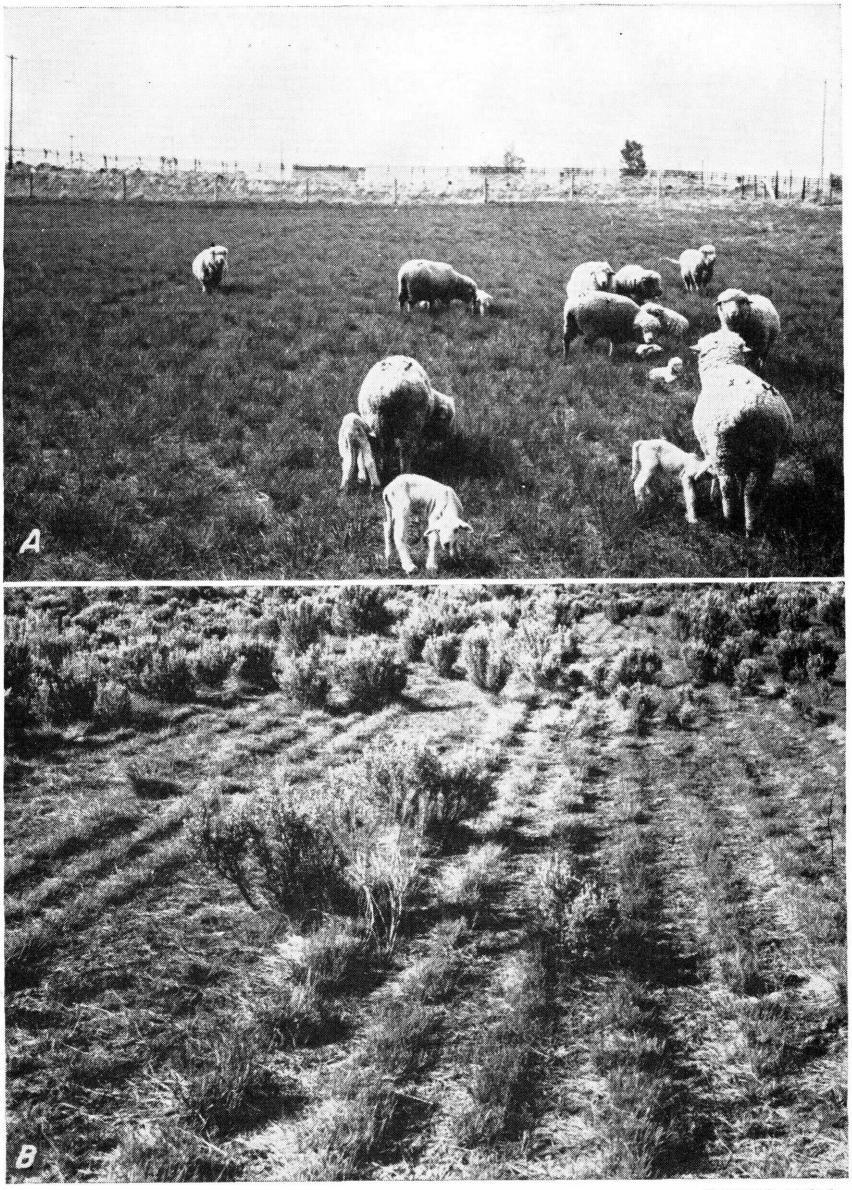

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FIGURE 18.—A complete sagebrush kill, a good cover of native or seeded forage plants, and good grazing management all prevent or help delay reinvasion by sagebrush. *A*, This area of former sagebrush range seeded to crested wheatgrass, photographed in 1945, is still sagebrush free, largely as result of good grazing management. *B*, A good stand of seeded grasses was established on this range, but extremely heavy grazing use for 5 years has weakened the grasses and sagebrush is invading and increasing rapidly.

COMMON AND SCIENTIFIC NAMES OF PLANT SPECIES MENTIONED

Grasses and Grasslike Plants

Brome, cheatgrass	*Bromus tectorum.*
Fescue, Idaho	*Festuca idahoensis.*
Wheatgrass, crested (Fairway and Standard)	*Agropyron cristatum; A. desertorum.*

Annual Weeds

Flixweed	*Sophia parviflora.*
Halogeton	*Halogeton glomeratus.*
Russian-thistle	*Salsola kali* var. *tenuifolia.*
Tumblemustard	*Norta altissima.*

Shrubs

Bitterbrush, antelope	*Purshia tridentata.*
Horsebrush, spineless*	*Tetradymia canescens* var. *inermis.*
Juniper, Utah	*Juniperus osteosperma.*
Rabbitbrush*	*Chrysothamnus* spp.
Pricklypear	*Opuntia engelmannii.*
Sagebrush	*Artemisia* spp.
Sagebrush, big	*A. tridentata.*
Sagebrush, black	*A. nova.*
Sagebrush, sand	*A. filifolia.*
Sagebrush, low	*A. arbuscula.*
Sagebrush, silver*	*A. cana.*
Sagebrush, threetip	*A. tripartita.*
Shadscale	*Atriplex confertifolia.*
Snowberry*	*Symphoricarpos* spp.

*Plants sprout quite heavily from stem base and roots.

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